Overview of EPRI (2004, 2006) GMM Review Project

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USGS National Seismic Hazard Map (NSHMp) Workshop on Ground Motion Prediction Equations (GMPEs)
for the 2014 Update
December 12, 2012

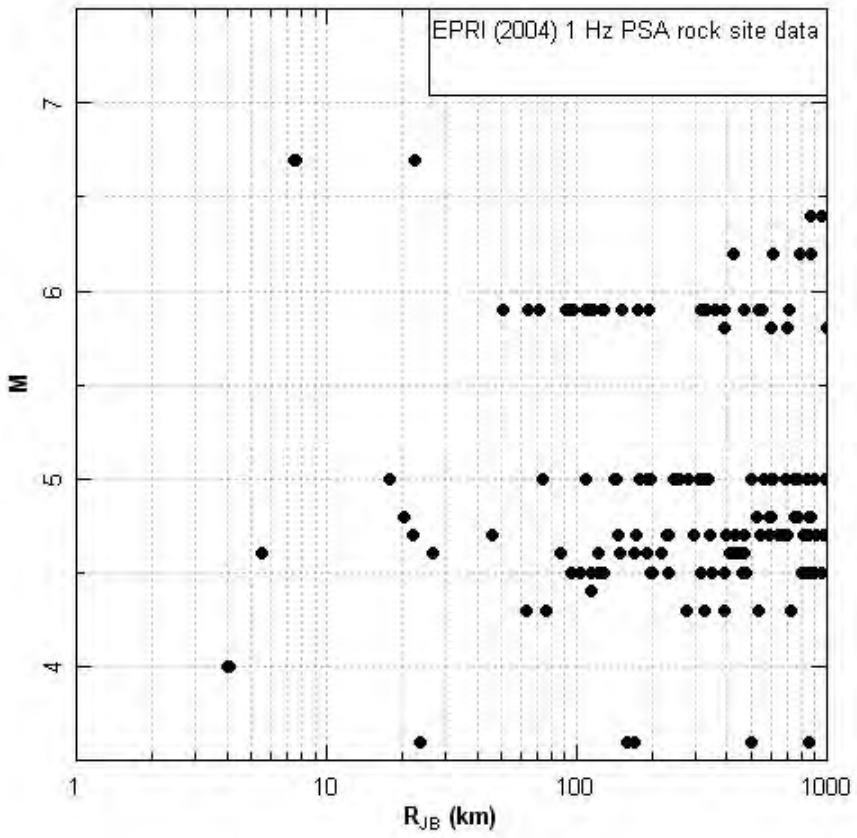
Purpose

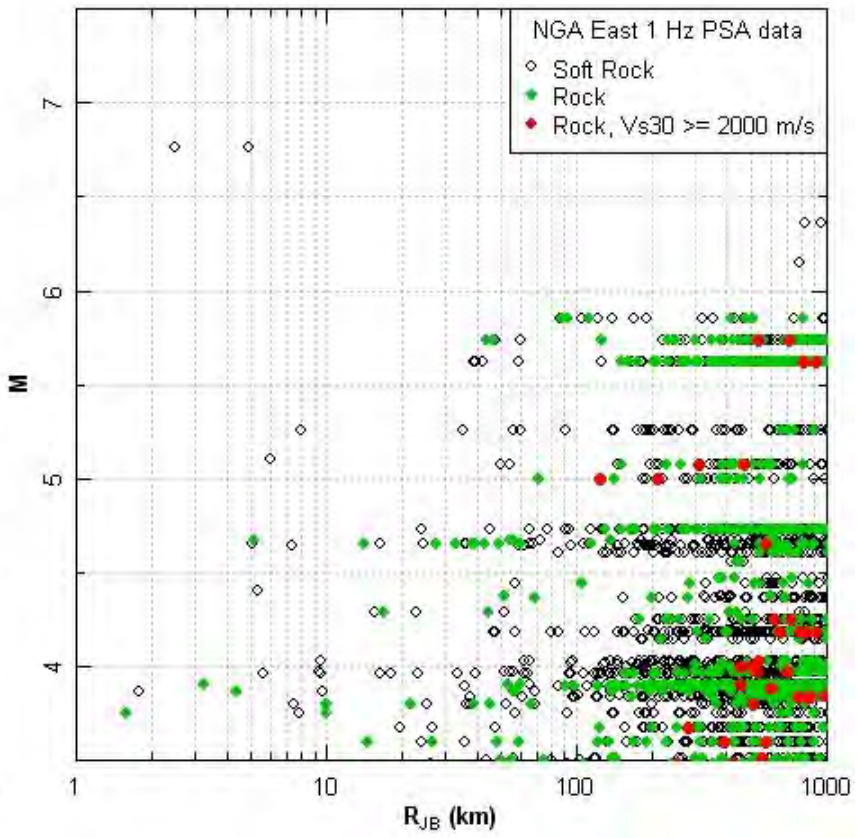
- Response to US NRC Letter 5054f requires calculation of Ground Motion Response Spectra (GMRS) for existing commercial nuclear power plant sites
- Calculations are to be based on the recently completed SSHAC 3 Central and Eastern United States Seismic Source Characterization (CEUS SSC) model (NUREG-2115)
- Results of the ongoing SSHAC 3 NGA-East Project will not be available in time to support the response
- Existing EPRI (2004) SSHAC 3 ground motion model (GMM) was completed about 10 years ago
  - Substantial increase in available ground motion data for CEUS
  - A number of newer GMPEs have been developed post 2003
- Review EPRI (2004/2006) in light of new data and models and, if judged appropriate, provide an interim update for use in responding to the 5054f request
- Not intended as a substitute for NGA-East

Phase 1 - Review

- Task 1: Develop Project Plan
- Task 2:
  - Review and process Ground-Motion Database
  - Review New CEUS GMPEs
  - Resource Expert and Proponent Interviews;
- Task 3: Obtain Shear Wave Velocity Measurements at Recording Stations;
- Task 4:
  - Test the EPRI (2004, 2006) Ground Motion Model (GMM) against new data and models
  - Decide if an update is needed

Comparison of EPRI 2004 and NGA East 1 Hz PSA Datasets





GMPEs Used in EPRI (2004) GMM

Cluster	Model Type	Models
1	Single Corner Stochastic (0.275/0.351)	Hwang and Huo (1997) Silva et al (2002) - SC-CS Silva et al (2002) - SC-CS-Sat Silva et al (2002) - SC-VS Toro et al (1997) Frankel et al (1996)
2	Double Corner Stochastic (0.312/0.399)	Atkinson and Boore (1995) Silva et al (2002) DC Silva et al (2002) DC - Sat
3	Hybrid (0.196/0.250)	Abrahamon & Silva (2002) Atkinson (2001) & Sadigh et al (1997) Campbell (2003)
4	Finite Source /Greens Function (0.217/0.000)	Somerville et al. (2001)

New Candidate Models

- Atkinson-Boore (2006 with 2011 revisions: AB06')
  - Recommended by Atkinson and Boore
- Atkinson (2008, with 2011 revisions; A08')
  - Recommended by Atkinson
- Pezeshk et al. (2011)
  - Recommended by Campbell and Pezeshk
- Silva et al. (2003):
  - nearly identical to Silva et al. (2002); treat as equivalent

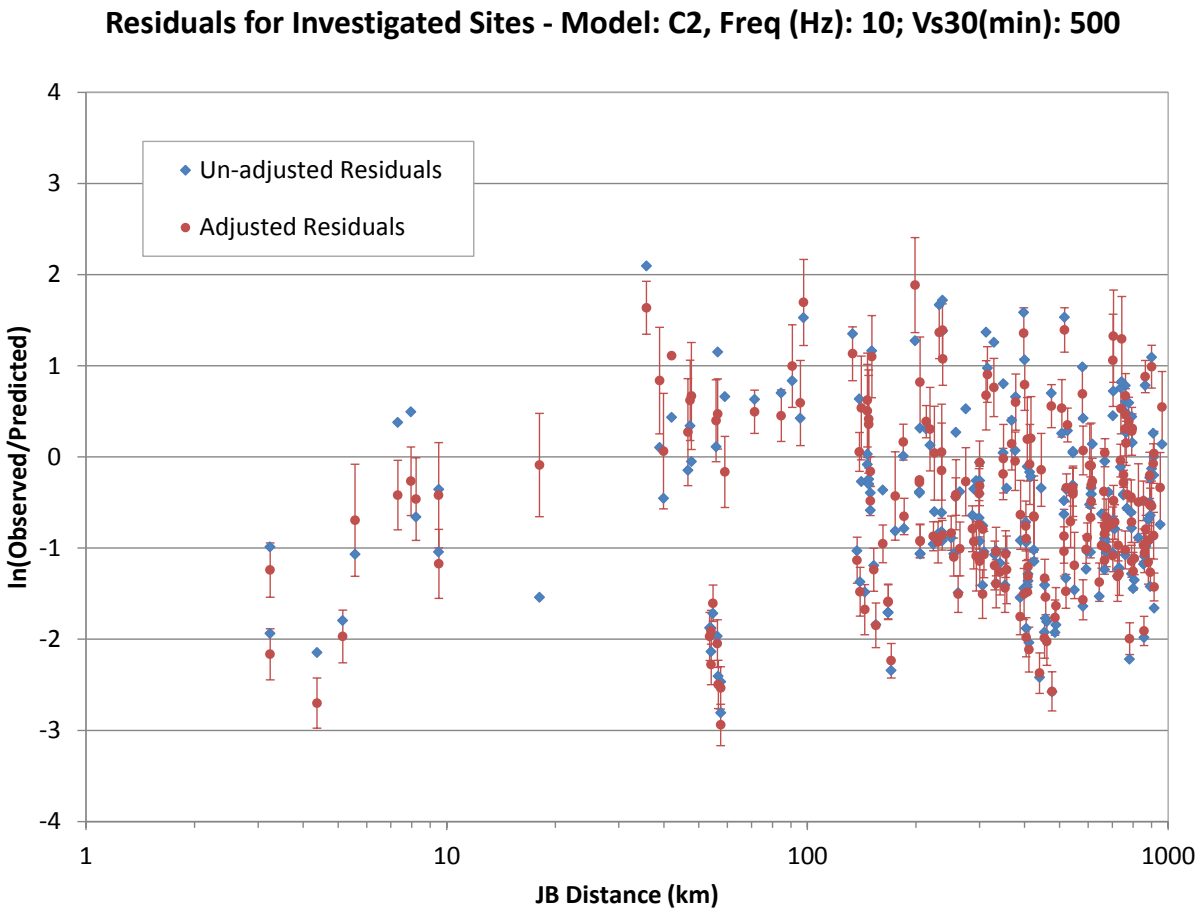
Task 3: Shear Wave Velocity Measurements

- Augment existing recording site data and ongoing USGS measurement program
- Measured shear wave velocities at 33 recording sites covering a range of locations in the CEUS with

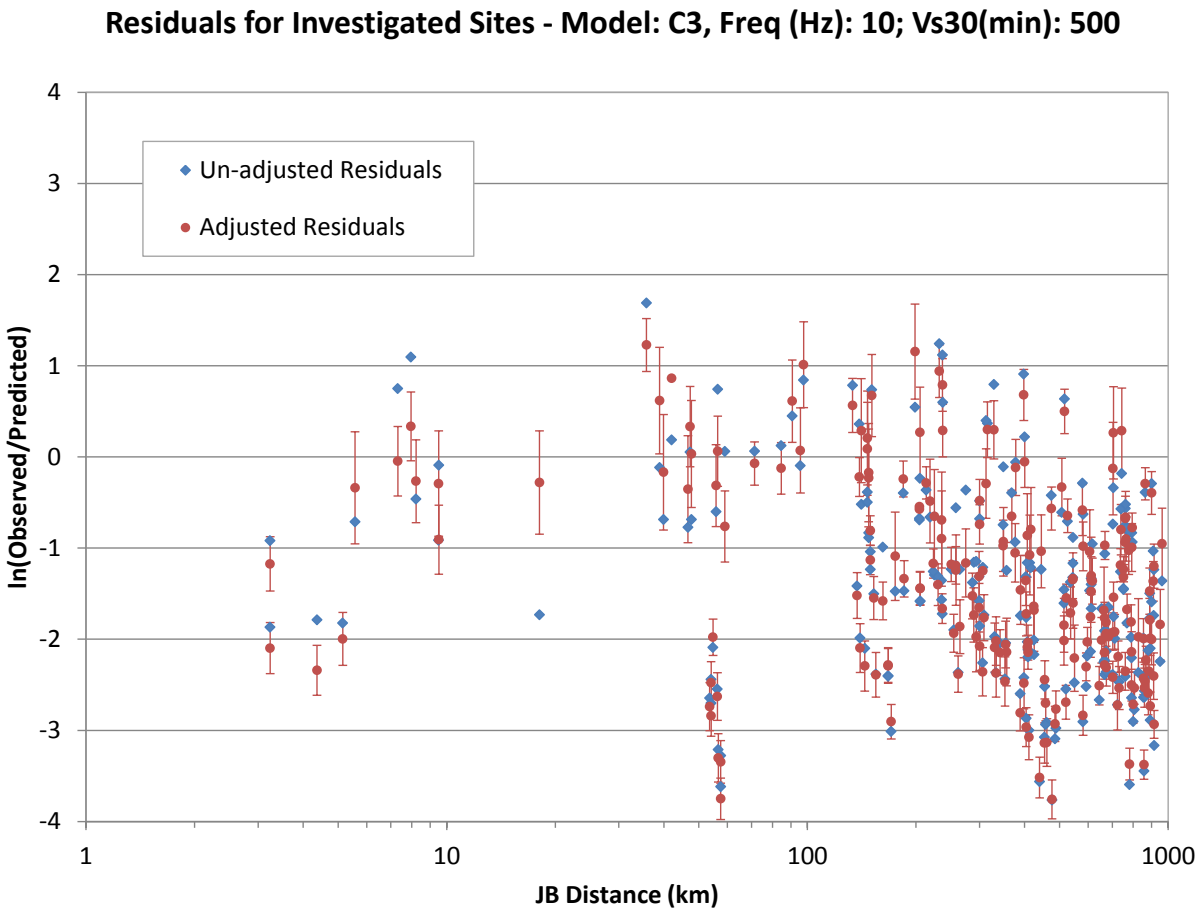
Task 4: Review of 2004 Model Versus Data

- Compute residuals of NGA East database relative to EPRI (2004) cluster median models
  - Use data for sites with measured VS30 and adjust residuals analytically
  - Use data from sites that can be classified as rock
- Results indicated over prediction of ground motions in some magnitude-distance-frequency ranges

Example for EPRI (2004) Cluster 2



Example for EPRI (2004) Cluster 3



Recommendation to Update

- Seven (7) of the thirteen (13) developers of the ground motion prediction equations (GMPEs) used in the EPRI (2004, 2006) GMM recommended that their GMPEs be replaced.
- There are three new GMPEs developed by ground motion experts during the past ten (10) years.
- Eighty percent (80%) of the earthquake records in a new ground motion database are from earthquakes that occurred after the development of the EPRI (2004) GMM.
- The EPRI (2004, 2006) GMM over-predicts ground motions at some magnitude-distance-frequency ranges important to nuclear power plant (NPP) probabilistic seismic hazard assessments (PSHAs).

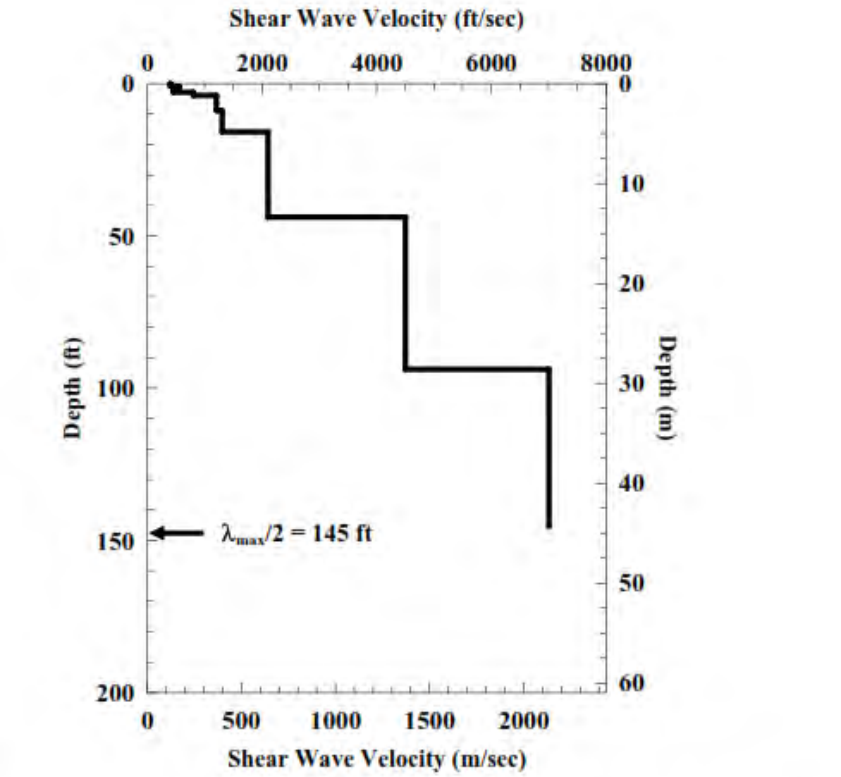
Phase 2 – Approach for Update

a. Use EPRI (2004) approach of grouping candidate models into clusters
b. Assess residuals of candidate models using NGA-East database
   - Analytical adjustment of data to EPRI (2004) reference site conditions (2800 m/s, kappa=0.006s) for stations with V_S profiles
   - Empirical adjustments for rock sites grouped into classes based on available information
c. Develop within-cluster weights using computed residuals
d. Fit weighted mean ln(PSA) for each cluster with an algebraic equation
e. Generate 3 GMPEs per cluster to represent within-cluster epistemic uncertainty
f. Develop cluster weights using fit to data and other considerations
g. Modify for Gulf Coast conditions
h. Update EPRI (2006) aleatory variability model using final version of NGA (2008) and preliminary results from NGA-West2

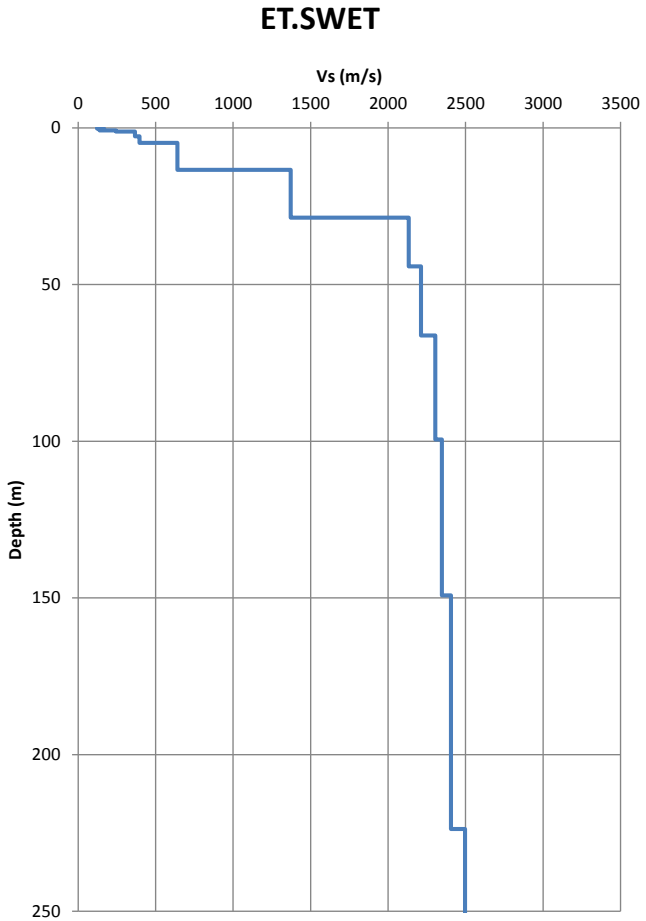
Draft New Clusters

Cluster	Model Type	Models
1	Single Corner Brune Source	Silva et al (2002) - SC-CS-Sat* Silva et al (2002) - SC-VS* Toro et al (1997) Frankel et al (1996) * Treated as one model for calculation of weights
2	Complex/Empirical Source $\sim R^{-1}$ Geometrical spreading < 70 km	Silva et al (2002) DC – Sat A08'
3	Complex/Empirical Source $\sim R^{-1.3}$ Geometrical spreading < 70 km	AB06' PZT11
4	Finite Source /Green's Function	Somerville et al. (2001); slightly different models for rifted and non-rifted

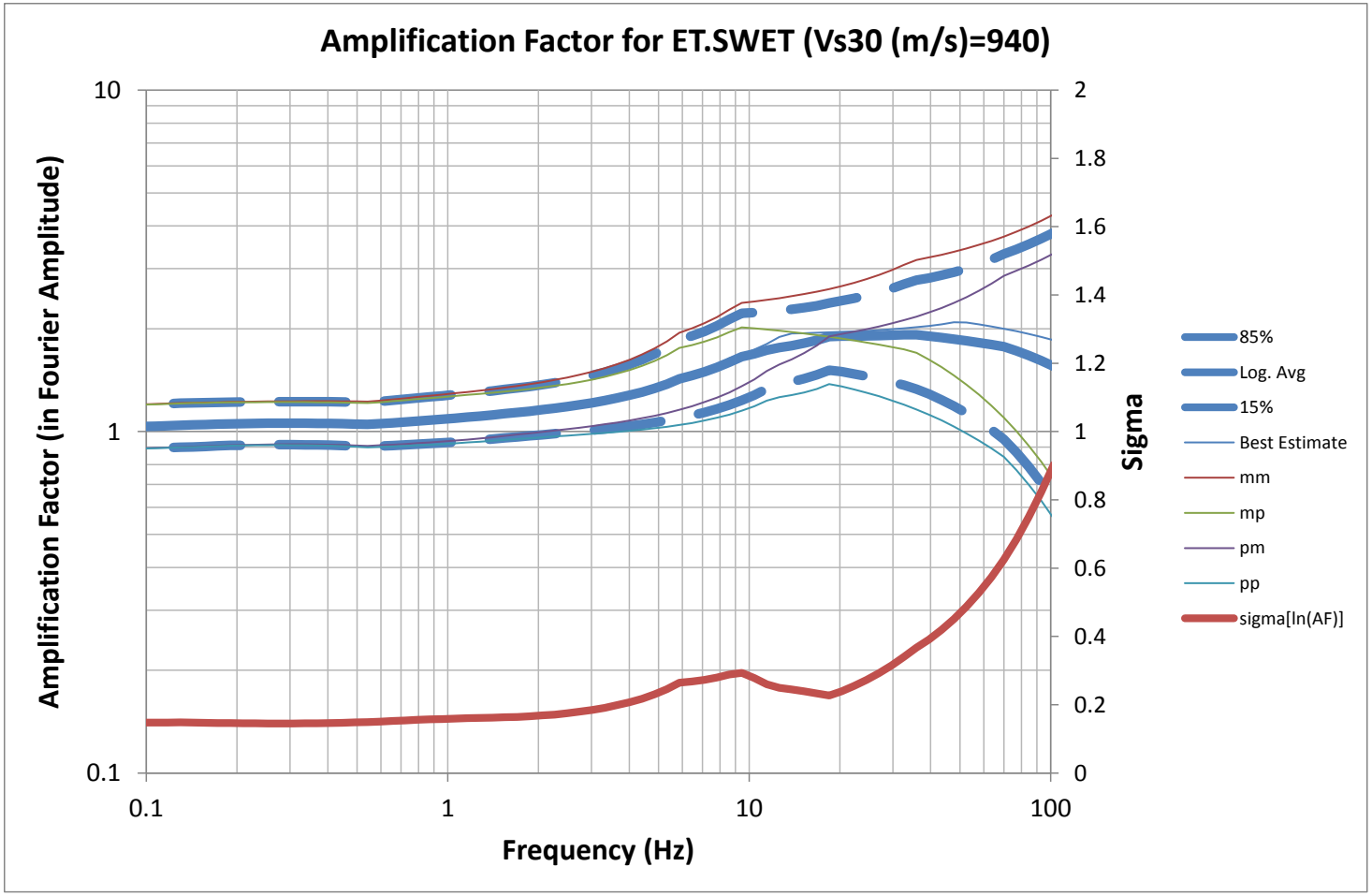
Example Data Used for Analytical Adjustment: ET.SWET (Tennessee)



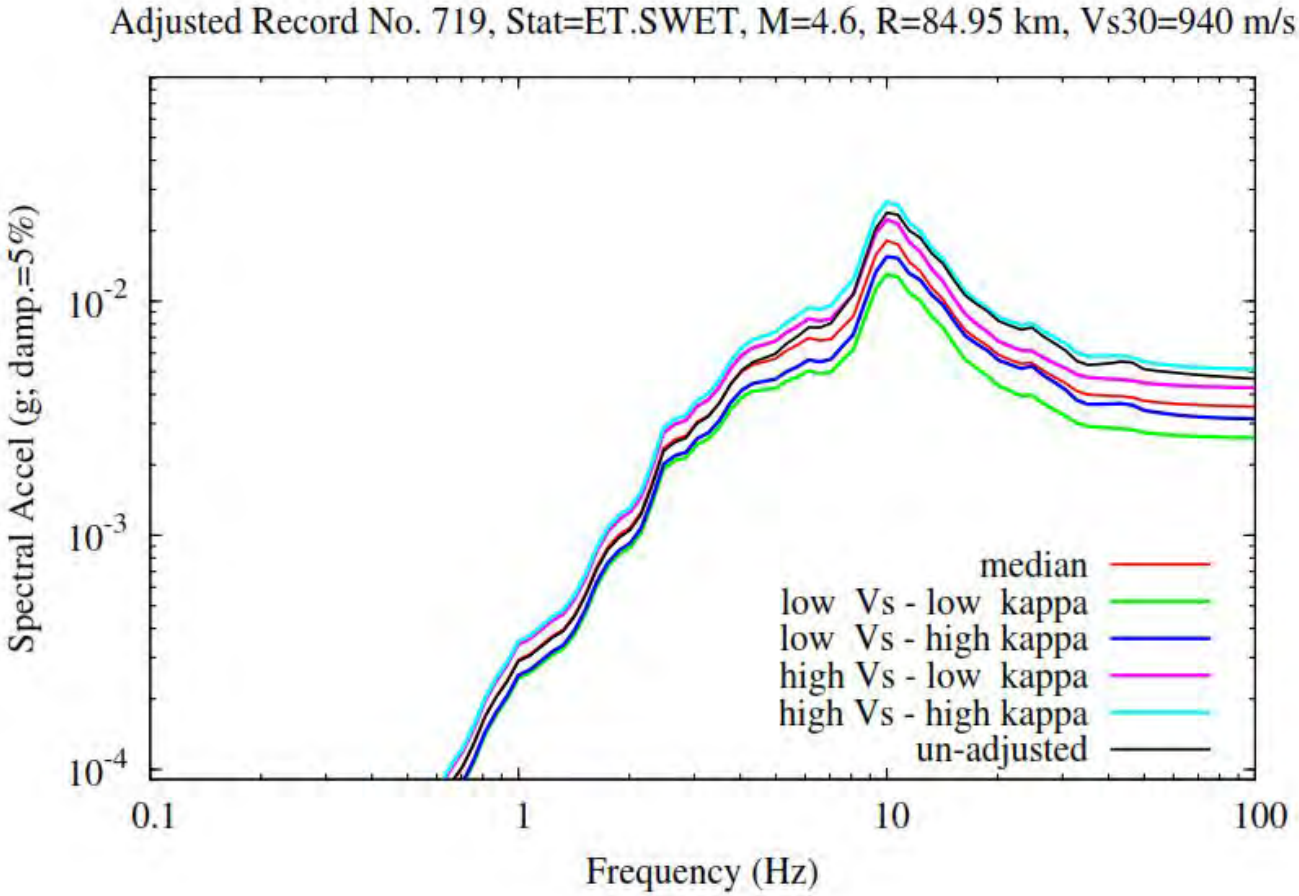
Shear Wave Velocity Profile Determined at Station ET.SWET by SASW Method



Example Analytical Amplification Factors Developed Using ¼ Wavelength Method Including Uncertainty in Vs and kappa



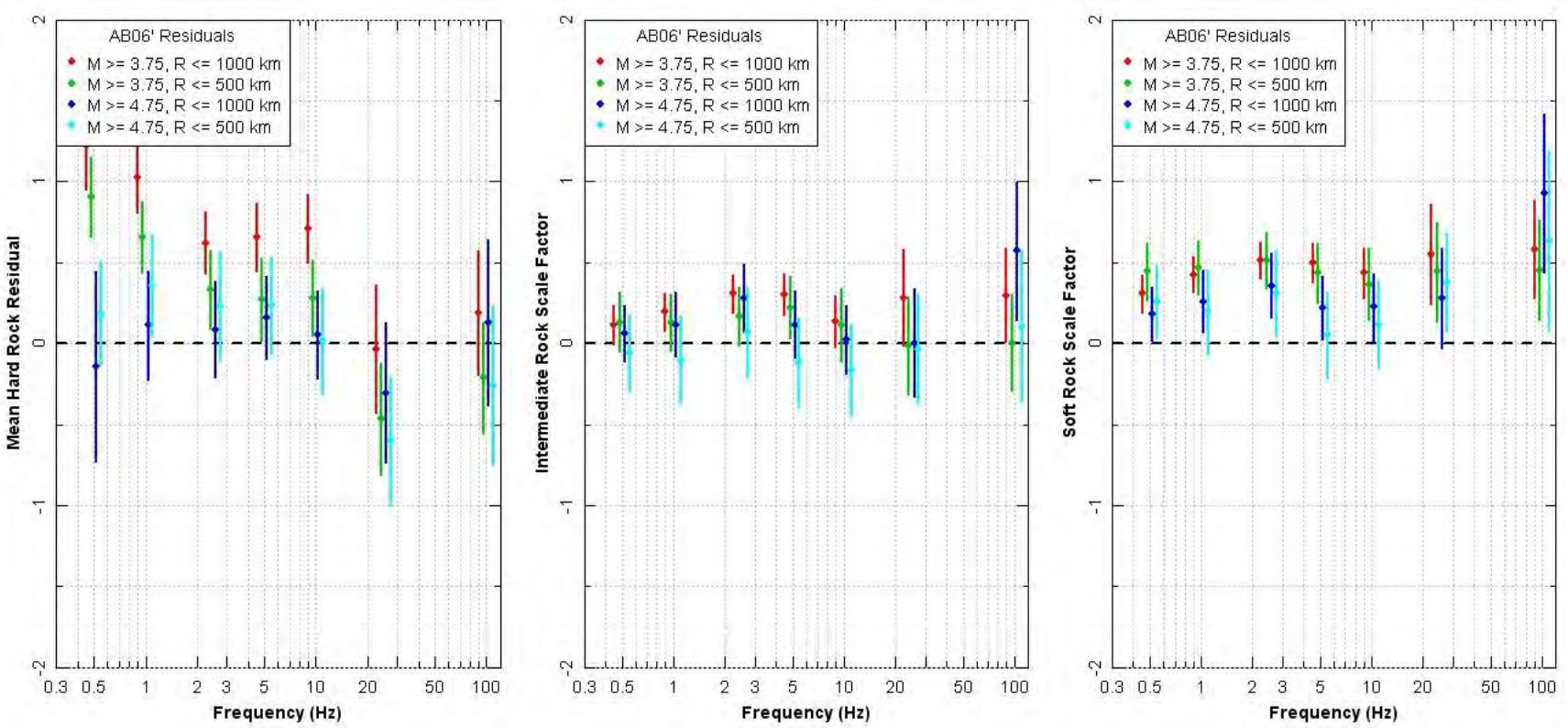
Example of Calculated Spectra



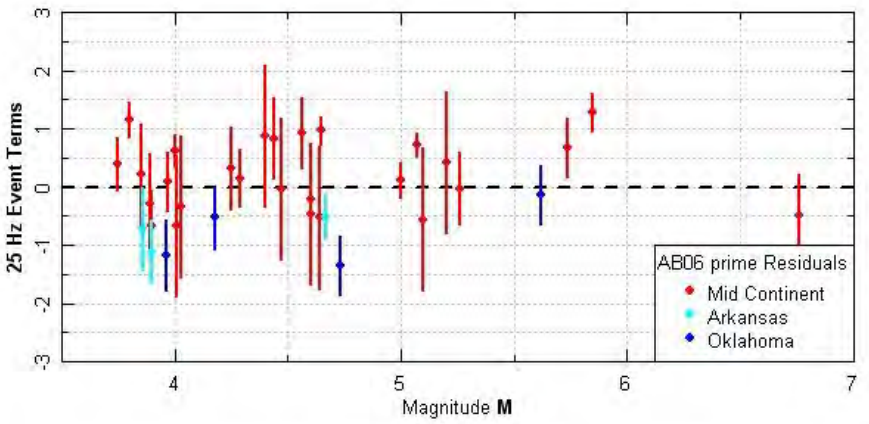
Empirical Adjustments – Site Classes

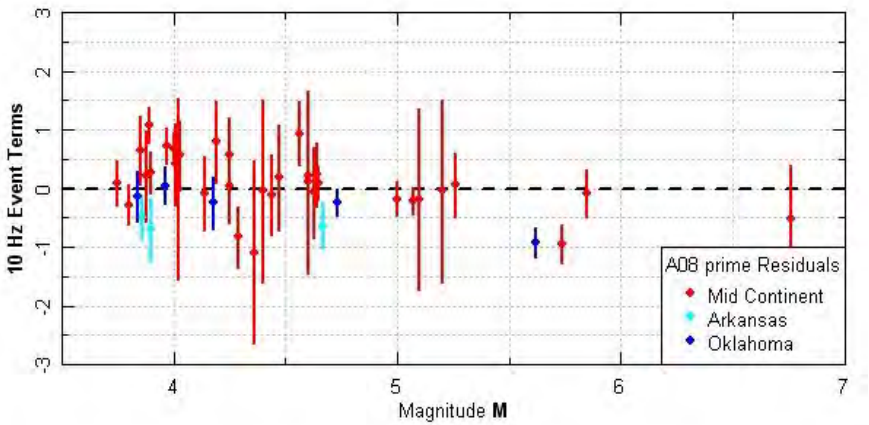
- Group rock sites into three classes based on available information
  - Hard rock: sites with measured or inferred $V_{S30} \geq 1900$ m/s
  - Intermediate rock: sites with measured or inferred V_{S30} 1,000 to 1,900 m/s or consisting of older rock types with unknown V_{S30}
  - Soft rock: sites with measured or inferred V_{S30} 500 to 1,000 m/s or consisting of younger/softer rock types with unknown V_{S30}

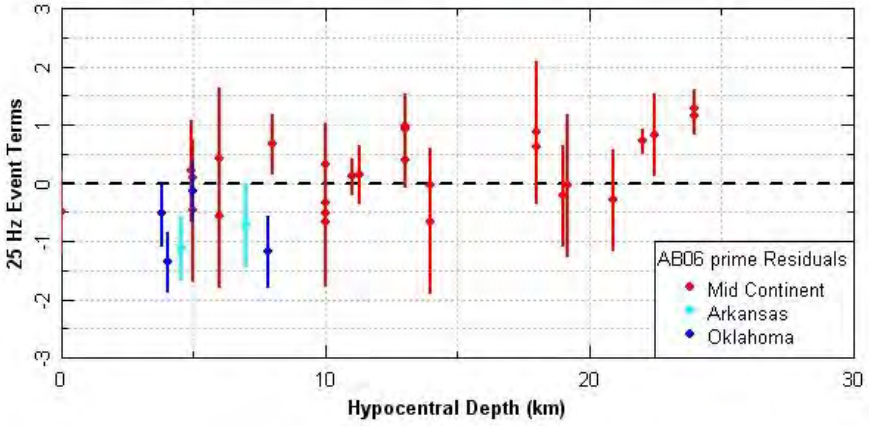
Fit Linear Model to Residuals Using Mixed Effects Allowing for Differences in Scaling Among Site Classes

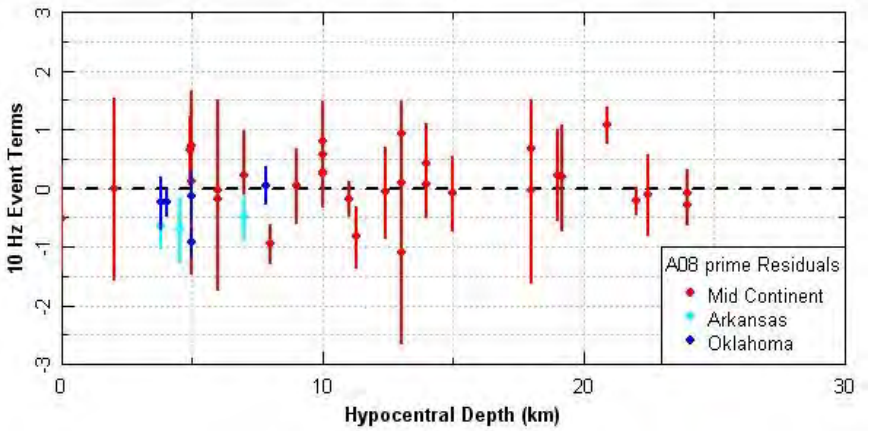


Analyzed Arkansas & Oklahoma Earthquakes for Potential Differences









Results of Fitting Residuals

- Only “Soft Rock” empirical scaling factor statistically significant
  - Use empirical factor to scale soft rock residuals
  - Use intermediate and hard rock data unscaled to compute weights
- Central Arkansas and Oklahoma earthquakes have lower event terms for 25 and perhaps 10 Hz
  - Lower motions statistically significant for 25 Hz and marginally significant for 10 Hz
  - Could be a source effect or a site effect (higher than average kappa)

Calculation of Within-Cluster weights

Formulation: Relative likelihood of observed data given model computed using mixed - effects covariance matrix with terms for:

- Inter-event (tau)
- Intra-event (phi)
- Uncertainty in site adjustment for common sites across earthquakes

$$L = \exp\left(-\frac{\boldsymbol{\varepsilon}^T \mathbf{V}^{-1} \boldsymbol{\varepsilon}}{2}\right)$$

4 levels of aggregation to obtain weights:

- M-R ranges (according to importance)
- Frequencies (25 Hz to 0.5 Hz, PGA not used)
- Approaches for site adjustment (analytical vs. empirical)
- With and without records from OK-AR earthquakes

Within Cluster Epistemic Uncertainty

- Plan to use envelope of model to model variability and constraints on median predictions provided by data
- Did not use parametric uncertainty of EPRI (2004) because of difficulty in defining correlations

Cluster Weights

- Data based weights computed using relative likelihood averaged over 6 frequencies
- Assessed weights based on assessment of how well the models in a cluster capture current understanding of magnitude and distance scaling
  - Data based weights are not enough as data is limited in magnitude range of interest and many of the newer models are calibrated on that data

Gulf Coast

- Refine region based on on CEUS SSC source regions and discussions with NGA-East path group
- Update Gulf Coast Q model developed from analysis of TA data
- Gulf Coast GMM will be developed using transfer function relative to Mid-Continent in same fashion as EPRI (2004)

Update of EPRI (2006) Aleatory Model

- EPRI (2006) examined potential for differences between WNA and CENA aleatory variability
  - Concluded that event-to-event (tau) may be slightly larger (0.03 units) and within-event (phi) should be similar or slightly smaller (0.03 units)
  - Used average of preliminary NGA results
- For updated model, adopted concept, but will use final NGA (2008) results and preliminary NGA-West 2 values

Status

- Draft Mid-Continent and Gulf Coast models being tested in hazard sensitivity calculations
- Model to be finalized by mid February, 2013
- Report to finalized by end of April, 2013

Acknowledgements

- EPRI – Sponsor of project
- PEER NGA-East Project – provided strong motion data base and shared data on site conditions, Vs, and crustal regionalization
- USGS – provided data on site Vs